M. Sc. Physics Examination, 2022

(2nd Year, 2nd Semester)

Plasma Physics

Paper – PG/SC/CBS/PHY/TH/301

Time : Two hours | Full Marks : 40

The figures in the margin indicate full marks.

Candidates are instructed to give their answers in their own words as fas as practicable.

Answer ***any four*** questions: 4×10=40

1. The behaviour of plasma medium near its equilibrium state can be described with the help of a dispersion relation $\omega = f(k)$, where ω is the wave angular frequency and k denotes the wave number. The dispersion relation for the propagation of an extraordinary electromagnetic wave through plasma is given by

$$\frac{c^2k^2}{\omega^2} = 1 - \frac{\omega^2{}_{pc}\omega^2 - \omega^2{}_{pc}}{\omega^2\omega^2 - \omega^2_{uh}},$$

where ω_{pc} is the upper hybrid frequency. And, c denotes the velocity of light in free space.

a) Write down the expression of ω_{pc}. Show that it has dimension $[T^{-1}]$.

b) Why the frequency ω_{uh} is called the 'hybrid' frequency?

c) Are there any 'cut-off' and 'resonance' present in the above dispersion relation? Identify them.

d) Roughly sketch a curve v_{ph}^2 / c^2 vs. ω, clearly showing the regions of wave propagation, where $v_{ph} = w / k$ denotes the phase velocity of the wave.

[(1+2)+1+4+2]

2. A plasma is immersed in an external uniform magnetic field which points along the x direction in a Cartesian coordinate system. Moreover, a uniform electric field is present along the z direction. We would like to focus on the dynamics of an ion (singly ionized) of charge q released at rest from origin.

a) Give a qualitative picture of the motion of the ion under the influence of both the uniform electric and magnetic fields.

b) Prove that the particle motion would be confined to the yz plane and the corresponding trajectory is cycloid.

c) Does the plasma drive any currents in the presence of both the uniform electric and magnetic fields?

d) If the external magnetic field is removed from the system, and we now consider the presence of a spatially varying oscillating electric field, i.e., $\vec{E}(r,t) = E(r)e^{i\omega t}\hat{e}_x$, then briefly describe the nature of the motion of the ion. 2+5+1+2

c) In Langmuir probe method, what is the basic principle to measure electron temperature and electron density?

d) Which method can be utilized to detect the end point during plasma etching? 2+4+3+1

a) Identify the nonlinear and dispersive terms present in the above equation.

b) State the nature of solution of the above equation in the absence of the term $\partial^3 u / \partial x^3$.

c) Show that the above KdV equation offers a single 'soliton' solution in the form:

$$u(x - Vt) = 3V \operatorname{sech}^2\left[\frac{\sqrt{V}}{2}(x - Vt)\right]$$

d) What is the physical significance of the parameter V introduced? 1+2+6+1

5. a) Establish Townsend's current growth equation in the presence of secondary processes. How the Townsend break-down criteria is related to the distance between the electrodes?

b) What makes plasma suitable for semiconductor material processing and other applications?

c) What are the advantages of AC discharge over DC charge? 6+2+2

6. a) What is the role of matching network in RF glow discharge system?

b) If you increase the power density (input parameter) of a RF sputtering system, what may the effect on the deposition rate of the material? You may draw a graph to show the variation and can explain.

3. The laboratory produced plasmas are generally confined in a system of finite size. Obviously, the electrons and ions strike the walls of the container due to their motions. Indeed, there are random particle fluxes of ions and electrons. It has been observed that, close to the walls, 'sheaths' are formed.

a) Initially more electrons reach the walls than ions. What is the reason behind this?

b) In the context of the theory of sheath formation, what do you mean by 'floating potential'?

c) Prove that the potential distribution across the sheath region in one space dimension x is given by

$$\phi(x) = \phi_w e^{-x/h}, \text{ where } h = \lambda_D \left(1 - \frac{k_B T_e}{m_i u_0^2}\right)^{-1/2}.$$

Here ϕ_w is the potential at the wall, λ_D is Debye length, T_e is the electron temperature, m_i is the ion mass, and u_0 is the directed (drift) velocity of ions.

d) Hence briefly discuss the 'Bohm sheath criterion'.

1+2+6+1

4. The celebrated KdV equation describing weakly nonlinear long wave propagation in dispersive media reads as

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + \frac{\partial^3 u}{\partial x^3} = 0, \text{ where } u \equiv u(x,t).$$